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# RESEARCH MEMORANDUM

## DESIGN AND EXPERIMENTAL INVESTIGATION OF LIGHT-WEIGHT BASES FOR AIR-COOLED TURBINE ROTOR BLADES

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

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## SUMMARY

The problem of air-cooled turbine rotor-blade weight reduction for aircraft gas turbines was investigated as part of the NACA turbine-cooling research program. A bulb-root-type blade-base design was achieved which utilized forming and brazing techniques in its manufacture and was combined with an aerodynamic profile identical to that used in a current axial-flow turbojet engine modified for air-cooling. A sample of this as well as other bulb-root-type designs was tensile-tested at a temperature of 750° F, the approximate air-cooled blade-base temperature during engine operation.

Samples of two designs, each weighing approximately 50 percent less than the comparable bulb-root-type air-cooled cast base, withstood tensile loads approximately as great as or greater than the centrifugal force (6480 lbs) imposed on the blade airfoil section during engine operation at rated speed. Samples of these designs were also endurance-tested in a jet engine modified for air-cooling. One design failed after two hours at 80 percent of rated test-blade tip speed and a coolant-flow ratio of 0.05. Another design sample was operated for a total of 15 hours (12 hrs at rated test-blade tip speed) at coolant-flow ratios of both 0.05 and 0.03 before failure occurred. Metallographic examination indicated that failure was probably caused by cracks introduced during the fabrication process, and it is believed that an alternate fabrication method can be developed which will eliminate such difficulties.

## INTRODUCTION

A major aspect of turbine-cooling research is the development of satisfactory air-cooled blades. Among the factors contributing to a satisfactory blade are maximum cooling effectiveness combined with minimum blade cooling-air pressure losses, the ability to function at turbine operating stress levels, and minimum weight. The phase of turbine-cooling research reported herein is directed toward reducing air-cooled blade weight with a view toward decreasing rotor rim stress and affording greater ease of blade fabrication.

Various methods of air-cooled blade weight reduction were discussed in reference 1. These methods consisted of variations in the cast blade base designs such as changing the number of base serrations and using thin (0.018 in.) untapered stock for the airfoil material. Consideration of air-cooled blades currently employed indicates that a major portion of the blade weight is concentrated in the base because of the relatively heavy type of cast base employed. Even the lightest of the cast base designs presented in reference 1 accounted for 43 percent of the total blade weight. Consequently, it appeared that a more drastic departure from current standards of air-cooled blade base design such as the use of a sheet-metal base structure might afford a means of achieving substantial reductions in total blade weight. Furthermore, consideration of current blade production processes indicated that considerable simplification might be achieved if the blade base as well as the blade profile was made by forming processes. 3283

In addition to reducing weight and possibly simplifying the fabrication procedure, use of a sheet-metal box-like base structure makes a large plenum chamber of the blade base. Distribution of cooling air to the blade airfoil section is thereby greatly simplified. Accordingly, a design and experimental investigation was initiated at the NACA Lewis laboratory to provide a light-weight air-cooled blade base which is capable of withstanding current turbine operating stress levels and which utilizes forming and brazing techniques in its manufacture.

The investigation described herein was concerned primarily with application to a specific engine, a current axial-flow turbojet engine modified for air-cooling. The airfoil section was nontwisted and utilized a corrugated-insert type of internal blade-passage configuration similar to that investigated in reference 2. Since the engine application was specified, the blade load requirements were also automatically specified. All blade design samples were tested statically, and those considered satisfactory on the basis of tensile tests were tested in a jet engine. Static tensile tests were made up to loads approximately equivalent to the centrifugal load imposed on the blade airfoil during rated-speed engine operation. The range of engine endurance operating conditions included tip speeds of 80 to 100 percent of rated test-blade tip speed and coolant-flow ratios of 0.03 and 0.05.

## DESIGN PROCEDURE

### Light-Weight Base Design Possibilities

In order to decrease air-cooled blade weight and utilize only forming and brazing techniques in blade manufacture, a radical departure from standard blade-base designs was indicated. This may be illustrated by consideration of the bulb-root-type cast air-cooled blade base shown in figure 1. Examination of this blade base indicates that a large portion of the total mass is concentrated above the neck over the bulb root. Since the blade is supported in the rotor on the cheeks of the bulb root below the necked-down section, the base material above this section serves only to transmit the airfoil load to the bulb root and provides a smooth blade-base platform for the passing gas flow. Consideration of the base geometry reveals that much of this material is dead weight and is not needed to transmit the airfoil loads to the bulb root. Consequently, design attempts were directed toward elimination of this nonstrategically placed material. Provision for suitable voids during casting in the base region where excess material exists would result in substantial weight reduction; however, the requirement of a base design utilizing forming and brazing techniques would not be fulfilled. Consequently, the possibilities of supporting the airfoil through the medium of a sheet-metal structure were investigated.

A variety of blade designs have been developed by other investigators (refs. 3 to 5). Some of these designs may readily utilize a sheet-metal base structure. Two general designs, a pinned-type blade base (ref. 4) and a bulb-root-type base, were considered in the investigation reported herein. The former type was investigated only cursorily because of the major alterations required in converting available turbine rotors to permit testing of such designs in a turbojet engine.

Three major design steps were taken in the effort to provide a bulb-root-type base design which utilized a sheet-metal structure. (1) The airfoil was attached only to a box-like sheet-metal shell which formed the outer contours of the base. (2) When this proved to be unsatisfactory because of base deformation under applied tensile loads, the airfoil was extended into the outer sheet-metal base shell and made an integral part of the inner base structure. (3) The design was altered to determine the minimum structural bracing of the inner base structure required to provide adequate base stability.

All the bulb-root-type designs investigated employed rectangular box-like structures. Since the airfoil is curved, a more direct load transmittal from all parts of the airfoil section to the base may be achieved if the base has a similar curvature. Uncooled blades with curved bases have been investigated at this laboratory. A curved-base design necessitates the provision of curved slots in the turbine disk.

For convenient blade insertion and removal, the boundaries of the blade slots in the disk rim must be concentric radii. A design of this type was not applicable to the engine application considered in this investigation because the required base configuration resulted in the intersection of adjacent blade slots in the disk rim.

## Design Specifications

A current axial-flow turbojet engine modified for air-cooling was 3283
chosen as the basis for providing the design specifications employed in this investigation. Each base was attached to an airfoil having an aerodynamic profile and internal passage configuration (0.010-in. corrugations and an island insert) identical to those employed in an air-cooled modification of the axial-flow engine. The blade-base dimensions were established by the blade profile, number of blades, and turbine rotor design of this engine. Design centrifugal load requirements were established by engine design specifications: speed, 8000 rpm; rotor tip diameter, 34.3 inches; blade span, 3.80 inches; and blade-shell metal distribution.

## Design Calculations

Calculations to determine whether the base designs would remain stable and not deform under the loads encountered in an engine application were virtually impossible to perform. The complex load distribution within the base and lack of knowledge as to the spring rates (radial deflection per unit load) of the sheet-metal base structure hamper such calculations. Therefore, adequate evaluation of the designs could only be achieved by experimental tests of design samples. In order to determine a suitable stress loading for application to sample blade-base designs in a static tensile test, calculations were made to determine the centrifugal force encountered by the blades in an engine application.

Although the blade base is also subject to centrifugal forces, these were not pertinent to the determination of the static tensile-test load. In the static tensile test of a blade design sample, the entire tensile load is necessarily transmitted through the braze attachment between the blade shell and the base. Therefore, the centrifugal forces exerted on the base would be inaccurately charged to the brazed attachment between the blade shell and base if they were included in the tensile-test load applied. In these calculations, only the volume of material in the blade shell, the corrugations, the island insert, and the braze metal were included. The total calculated volume of shell and insert was increased by 18 percent to allow for the braze metal in this type blade as dictated by fabrication experience. The resulting calculated centrifugal load was 6480 pounds.

## APPARATUS AND PROCEDURE

Samples of the blade designs were first tensile-tested to provide an indication of their strength characteristics. If the results were satisfactory, the blades were endurance-tested in a jet engine modified for air-cooling.

### Tensile Tests

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A standard 120,000-pound hydraulic tensile-testing machine was employed for testing the samples of the various blade designs. Figure 2 illustrates a typical tensile-test specimen and the special grips employed. The lower grip was provided with grooves similar to those in a rotor rim which matched the blade base. The upper grip was brazed to the blade profile. A platinum-wound resistance-type furnace was attached to the tensile-test machine so as to surround the specimen. The blade-base temperature was raised to 750° F and was stabilized at this value for approximately an hour before pulling. Blade-base temperature was indicated by a thermocouple spot-welded to the blade base at the location indicated in figure 2. Each blade tested was pulled until base failure occurred or until visible deterioration of any portion of the base or blade indicated an imminent failure.

### Endurance Tests

Engine modifications. - A production turbojet engine was modified to permit endurance operation of light-weight blade-base design samples. Cooling air was supplied to the test blade from an external source through an arrangement essentially the same as that described in reference 6. Briefly, blade cooling air was introduced through the engine tail cone to a tube concentric with the center line of the turbine rotor. From this tube, air was delivered to the test blade through one of two radial tubes welded to the downstream rotor face. Figure 3 shows a photograph of the rotor installation. The installation shows one light-weight test blade in position and the remaining standard uncooled blades mounted in the rotor. The rotor fir-tree serrations were filled in at the test-blade location and new grooves machined in the turbine rotor to accommodate the bulb root employed in the light-weight blade design. The engine employed for endurance testing of the light-weight blades was a readily available centrifugal-compressor type and was used essentially as a hot spin rig. The rated blade-tip speed of the test engine exceeded that of the axial-flow engine for which the test-blade profile was designed, thus providing a satisfactory test range of blade-tip speed. It may be noted in figure 3 that the test blade was installed backwards (trailing edge forward) in the test engine. This installation was necessary because the direction of rotation of the test engine was opposite to that of the axial-flow engine for which the airfoil was designed.

Engine operation. - Samples of specific light-weight designs were investigated in an engine at blade-tip speeds equivalent to those encountered in the axial-flow engine for which the blade profile was designed. Speeds equivalent to 80, 90, and 100 percent of rated blade-tip speed for the axial-flow engine were set and coolant-flow ratios of 0.05 and 0.03 were employed. A turbine-inlet gas temperature level similar to that encountered in the axial-flow engine at the test tip speeds was also provided. An adjustable exhaust nozzle provided variations in the exhaust-nozzle opening and thus permitted changes in turbine-inlet gas temperature at a given engine speed. The uncooled-blade temperature was 3283
measured at the leading edge of two reference blades (fig. 3), and during operation uncooled-blade temperature data were compared with available blade temperature data obtained in the uncooled axial-flow engine at similar speeds and compressor-inlet conditions to provide an additional check on the gas temperature level. Blade cooling-air temperature was measured within the air tube welded to the rotor face. For an initial test it was not considered desirable to thermocouple the cooled test blade, since slotting the blade surface to install thermocouples might weaken the sheet-metal structure sufficiently to affect the endurance results. Endurance operation was periodically interrupted to permit visual inspection of the test blade.

## RESULTS AND DISCUSSION

The sheet-metal bulb-root-type base design underwent a series of changes in order to achieve a satisfactory design on a strength basis. These designs are discussed in chronological order. Then, the results obtained with the pinned-type base are presented. Finally, a discussion of weight reduction utilizing light-weight bases is presented.

### Sheet-Metal Bulb-Root-Type Air-Cooled Base Designs

Design 1. - The original bulb-root-type air-cooled base design, which is illustrated in figure 4, consisted of an outer base shell, an inner base shell, a base plate, and two end plates. The shells and end plates were formed from 0.030-inch sheet and the bottom plate was cut from 0.125-inch stock. Since the blade was to be air-cooled, blade base temperatures were not expected to exceed 750° F. Consequently, SAE 4130 or 4340 steel was considered adequate for all base parts. Both the inner and outer base shells were bent around the base plate, and two rectangular openings were provided to admit cooling air. The outer base shell maintained the contour of the grooves machined in the turbine rotor rim and was provided with a filleted cut-out in its upper surface to accommodate the blade aerodynamic profile. If the airfoil is assumed to be a rigid member, the entire airfoil load is transmitted in shear through the outer and inner base shells to the supporting base plate and thence to the rotor rim.

A sample of this design was fabricated by furnace brazing the entire assembly with copper in a controlled atmosphere (dry hydrogen). A complete failure of most of the brazed joints occurred during the tensile test at a 2440-pound load, approximately 38 percent of the calculated design blade centrifugal load. A summary of the conditions and results of tests conducted with this and all subsequent blade samples investigated is presented in table I. The failed sample is shown in figure 5. The aerodynamic section of the blade was pulled away from the base, and
3283 the base was deformed on the side of the airfoil suction surface. The deformation shown in figure 5 illustrates the problem of base instability and was typical of that encountered during tensile tests with subsequent base design samples.

Design 1, modification 1. - In view of the failure of the brazed joints in the original blade design sample, an all-welded construction was considered. The structural design of the base was essentially unchanged; however, in order to permit assembly after welding, the outer base shell was split as shown in figure 6(a). The outer base shell was welded to the inner shell at all points possible, and both shells were welded to the bottom plate along the edges of the rectangular cooling-air inlet openings. End plates and the blade aerodynamic section were also welded to the base. A sample of this design modification failed during the tensile test at a 4600-pound load. Although this result was more favorable than that obtained with the first blade sample tested, the applied load was still 29 percent below design requirements, and the necessity for further altering the original design was apparent.

Design 1, modification 2. - Consideration of the failures encountered indicated that a more rigid base might be achieved without substantially altering the original design concept merely by the addition of cross-chord base stiffeners. In order to keep the additional weight to a minimum, only one 0.060-inch stiffener was fitted and welded to the inner base shell contour at the midchord position. This modification is illustrated in figure 6(b). The assembly was welded and those joints which were difficult to weld were filled in by a silver braze compound applied with a torch. Failure of a sample of this design modification occurred at an applied tensile load of 3400 pounds. The fact that this design modification did not provide as favorable results as the all-welded structure without the base stiffener (modification 1) was attributed to welding difficulties encountered during fabrication. Nevertheless, it was believed that a more drastic departure from the original design would be required in order to satisfactorily transmit the blade load without base deformation; therefore, the second major design step was initiated.

Design 2. - All the previous designs provided for attachment of the airfoil directly to a filleted cut-out in the outer base shell. In these designs the inner base shell reinforced the outer shell but did not attach directly to the airfoil. Design 2 (fig. 6(c)) provided for extension of the greater portion of the airfoil contour into the outer base shell so that it attached directly to the base plate. Thus, the airfoil load was transferred to the base plate more directly. This is shown most clearly by comparison of the inner base shell structure for designs 1 and 2 (figs. 4 and 6(c), respectively) at the midchord position on the pressure-surface side. Near the suction-surface leading and trailing edges where it was impossible to extend the airfoil so that it would attach directly to the base plate, the airfoil was simply brazed to the filleted cut-out in the outer shell. The outer base shell was also 3283 furnace-brazed in a controlled atmosphere to the inner base structure and to the airfoil contour at all points possible. A sample blade of this design failed in tension under an applied load of 4540 pounds by rupture of the inner base shell, indicating no improvement over the best previous design.

Design 3. - In view of the continued base deformation encountered at subdesign loads, further design attempts were made to provide suitable base stability. The principle of extending as large a portion of the airfoil contour as possible so that it could attach directly to the base plate was maintained. One design which attempted to provide greater base stability is illustrated in figure 6(d). The base plate was shortened and end blocks were provided which attached to each end of the base plate. The end blocks were equipped with recesses contoured to receive the airfoil leading- and trailing-edge sections. In assembly, the base plate was inserted into the base section, which was extended from the airfoil. The end blocks were then placed in position and all the joints welded. In this design, the end blocks together with the base plate became the primary base support, and it was intended that the airfoil be anchored directly to the major supporting member of the base around its entire circumference. A split outer base shell, which maintained the turbine rotor rim contour, was welded around the base assembly.

A sample of this design was pulled to the limit of the chosen scale (6000 lbs) in the tensile-test machine without visible deformation of the blade base. A second sample of this design was installed in an engine; after 2 hours of operation at 80 percent of rated test-blade tip speed, failure occurred.

Although a large contact area existed between the end blocks and the airfoil leading- and trailing-edge sections along the suction surface, only a relatively small part of the airfoil leading- and trailing-edge sections along the pressure surface contacted the end blocks. Thus, the strength of this design, which attempted to firmly anchor the entire base section of the airfoil to the supporting base member, was limited by the amount of contact surface available. A larger contact area may be provided between the airfoil pressure-surface leading- and trailing-edge sections and the end blocks by increasing the size of the end blocks; however, this results in added weight.

Design 4. - The final design attempt to obtain satisfactory base stability is illustrated in figure 6(e). Again the principle of attaching the airfoil as directly as possible to the supporting base plate was maintained. Several cross-chord base stiffeners were utilized in this design. The base plate was separated into four sections by three such stiffeners, which were 1/8-inch thick and had the same contour as the serrations in the rotor rim. Two end plates were provided which had the same contour as the stiffeners but were only 0.030-inch thick. The inner base shell was curved to fit around the base plate sections and slotted to accommodate the stiffeners. The outer base shell simply consisted of a cap which fitted over the stiffeners and a portion of the inner base shell. Its only purpose was to provide a smooth blade base contour for the gas flow in a turbine rotor installation. The airfoil fitted into the contoured inner base shell. For assembly, the base plate sections were first inserted into the curved inner base shell. Next, the stiffeners were inserted into the slots provided in the inner base shell. The cap and end plates were fitted in place and the airfoil placed into the contoured opening provided in the upper portion of the inner base shell. After the parts were tack-welded together, the entire assembly was Nicrobrazed in a furnace. A sample of this design was tensile-tested to 7800 pounds, which is about 20 percent above the calculated blade centrifugal load. No visible base deformation occurred; however, the blade shell showed signs of being pulled away from the base at this load and the test was discontinued. A second sample of this design was endurance-tested in an engine. Figure 7 shows the test blade in the test rotor after 10 hours of endurance operation. No base deformation is apparent. The engine was operated as shown in table I. After 15 hours of operation, failure occurred. Seven hours of this total were obtained at rated test-blade tip speed and a coolant-flow ratio of 0.05; 5 hours were obtained at rated test-blade tip speed and a coolant-flow ratio of 0.03. Failure occurred as the operating point was being changed to 110 percent rated test-blade tip speed.

An enlarged photograph of the failed blade base is shown in figure 8. The portion of the blade-base structure near the leading edge is exposed. From about the midchord to the trailing edge, the airfoil broke away leaving the base intact. In order to properly evaluate this failure, a metallographic examination was conducted. The examination indicated that failure probably resulted from cracks in the cross-chord stiffener. Separation progressed through the brazed junctions between the stiffener and inner base shell. The Nicrobraz at the airfoil inner base shell junction showed grain boundary penetration which contributed toward weakening the assembly but was not believed to be the primary cause of failure. Weakness in the cross-chord stiffener and end plate resulted from tack welding these parts to the inner base shell. Tack welds were employed to hold the base parts in position prior to brazing. It is believed that welding either cracked the stiffener and end plate or embrittled the material so that a crack formed upon subsequent brazing.

A similar crack was noted in another cross-chord stiffener adjacent to a tack weld. Use of an alternate fabrication procedure which employs jigs rather than tack welding to hold the parts in position prior to brazing would eliminate these welding cracks and could readily be developed. 3283

## Air-Cooled Pinned-Type Base Design

The only pinned-type base design considered in this investigation is illustrated in figure 9. The lower part of the airfoil was flared. A sheet-metal base cap fitted over and was brazed to the flared airfoil section. The blade was to be supported in a disk through extensions of the base cap which fit between holes drilled axially through the disk and cylindrical pins. Since the blade base overhangs the turbine disk shown in the illustration because of the relatively long chord of the airfoil employed in this investigation, cooling-air leakage from the overhang may be reduced by providing a fillet ring as shown in the figure. A sample of this base design employing the same airfoil section as that utilized throughout the investigation was fabricated and tensile-tested. In order to facilitate observation of base deformation, the test was conducted at room temperature. Failure occurred at a 5350-pound load, approximately 18 percent less than the blade design centrifugal load. The blade sample after failure is shown in figure 10. The base cap was ruptured, but no deformation occurred in the region of the pins, a matter of interest since pinning as a method of blade attachment may be applied in conjunction with other types of blade base designs.

## Weight-Reduction Considerations

The weight reductions achieved with the sheet-metal bulb-root-type base designs considered in this investigation as compared with the cast base were appreciable. Base design 1, although unsuccessful strength-wise, represented a weight reduction of approximately 65 percent. Designs 3 and 4, which were satisfactory in static tests and which were tested in a jet engine, provided bases weighing, respectively, 47 and 45 percent less than the comparable cast base. It may be possible to achieve still greater weight reductions with base design 4 and obtain satisfactory operating results merely by decreasing the thickness of the cross-chord stiffeners.

Although the blade-weight reduction achieved by substitution of sheet-metal base structures is appreciable, it should be noted that further decreases may be achieved by other methods. One such method is to decrease the material employed within the blade cooling passage. Various internal cooling passage configurations have been evolved. Some result in heavier blades than others. Major reductions in blade weight, however, cannot be achieved simply by altering existing internal passage configurations because any such alterations involve consideration of pressure-drop losses as well as blade cooling effectiveness. Another effective method whereby turbine blade weight may be reduced is by use of small-chord high aspect-ratio blades. The effectiveness of this method is less for cooled blades than for solid blades; however, design effort should be directed toward providing short-chord high aspect-ratio blades to the limit that cooling, blade fabrication, and other considerations will permit.

The preceding weight comparisons deal exclusively with the base weights of designs evolved in this investigation and the comparable cast base for a current axial-flow engine modified for air-cooling. The effect of base-weight reduction upon total air-cooled blade weight is also of interest. In the case of design 4, the 45-percent reduction in base weight resulted in a 17-percent decrease in weight per blade.

A further weight comparison of interest is that between a complete set of blades utilizing sheet-metal base design 4 and a complete set of standard uncooled blades for the engine under consideration. These weights are somewhat influenced by the different numbers of blades which make up a complete cooled rotor and a complete uncooled rotor. A larger axial chord was specified in designing the air-cooled blades, while approximately the same solidity as occurred with the solid blades was maintained in order to achieve comparable aerodynamic performance. As a result, the air-cooled rotor design had 72 blades as compared with 96 for the standard rotor. The total blade-weight reduction of the cooled rotor in comparison with the uncooled rotor was 38 percent.

## SUMMARY OF RESULTS

The following results were obtained from an investigation designed to provide a light-weight air-cooled blade base which utilized forming and brazing techniques in its manufacture and was capable of withstanding current turbine operating stress levels:

1. Samples of two designs withstood tensile loads approximately as great as or greater than the centrifugal force (6480 lbs) imposed on the blade airfoil section during engine operation at rated speed.

2. A sample of the most favorable design was endurance-tested in an engine for a total of 15 hours (12 hrs at rated speed) at coolant-flow ratios of both 0.05 and 0.03 before failure occurred. Metallographic examination indicated that failure was probably caused by cracks introduced during the fabrication process.

3. A 45-percent reduction in base weight over that of the comparable air-cooled cast base was achieved with the most favorable design.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, May 7, 1954 3283

## REFERENCES


1. Moseson, Merland L., Krasner, Morton H., and Ziemer, Robert R.: Mechanical Design Analysis of Several Noncritical Air-Cooled Turbine Disks and a Corrugated-Insert Air-Cooled Turbine Rotor Blade. NACA RM E53E21, 1953.

2. Bartoo, Edward R., and Clure, John L.: Experimental Investigation of Air-Cooled Turbine Blades in Turbojet Engine. XII - Cooling Effectiveness of a Blade with an Insert and with Fins Made of a Continuous Corrugated Sheet. NACA RM E52F24, 1952.

3. Petrick, E. N.: A Survey of German Hollow Turbine Blade Development. Pt. 1 - Initial Investigation and Developments. Purdue Univ., Purdue Res. Foundation, pub. by USAF-AMC, Wright-Patterson Air Force Base, Dayton (Ohio), Oct. 1949. (USAF Contract W33-038-ac-17625.)

4. Petrick, E. N.: A Survey of German Hollow Turbine Blade Development. Pt. II - The Design Features and the Production of Hollow Turbine Blades and Hollow Turbine Rotors for Turbosuperchargers and Turbojet Engines. Purdue Univ., Purdue Res. Foundation, pub. by USAF-AMC, Wright-Patterson Air Force Base, Dayton (Ohio), Dec. 1949. (USAF Contract W33-038-ac-17625.)

5. Petrick, E. N.: A Survey of German Hollow Turbine Blade Development. Pt. III - Turbine Blade Vibrations; Considerations on the Improvement of Hollow Blade Designs. Purdue Univ., Purdue Res. Foundation, USAF-AMC, Wright-Patterson Air Force Base, Dayton (Ohio), Mar. 1950. (USAF Contract W33-038-ac-17625.)

6. Ellerbrock, Herman H., Jr., and Stepka, Francis S.: Experimental Investigation of Air-Cooled Turbine Blades in Turbojet Engine. I - Rotor Blades with 10 Tubes in Cooling-Air Passages. NACA RM E50I04, 1950.

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TABLE I. - SUMMARY OF OPERATING CONDITIONS AND RESULTS OF EXPERIMENTAL INVESTIGATION

| Air-cooled sheet-metal base designs | Static tensile tests | | | | Rotating endurance tests | | |
|---|---|---|---|---|---|---|---|
| | Blade-base temperature, °F | Maximum applied load, lb | Design load (blade airfoil), lb | Results | Engine tip speed, percent of rated | Turbine-inlet temperature obtained, °F | Results |
| 1 (Original bulb-root type) | 750 | 2440 | 6480 | Base failed | | | |
| 1 (Modification 1) | 750 | 4600 | | | | | |
| 1 (Modification 2) | 750 | 3400 | | | | | |
| 2 | 750 | 4540 | | | | | |
| 3 | 750 | 6000 | | No visible base deformation | 80 | 1175 | Failed at base after 2 hrs |
| 4 | 750 | 7800 | | No visible base deformation | 80 | 1175 | 2 hrs; coolant-flow ratio, 0.05 |
| | | | | | 90 | 1370 | 1 hr; coolant-flow ratio, 0.05 |
| | | | | | 100 | $^{a}1510$ | 1 hr; coolant-flow ratio, 0.05 |
| | | | | | 100 | $^{a}1385$ | 6 hrs; coolant-flow ratio, 0.05 |
| | | | | | 100 | $^{a}1385$ | 5 hrs; coolant-flow ratio, 0.03 |
| | | | | | 110 | | Base failed while setting operating point |
| 5 (Pin base) | Room | 5350 | | Base failed | | | |

[a]Maximum values obtainable with engine on days operated.

[redacted]

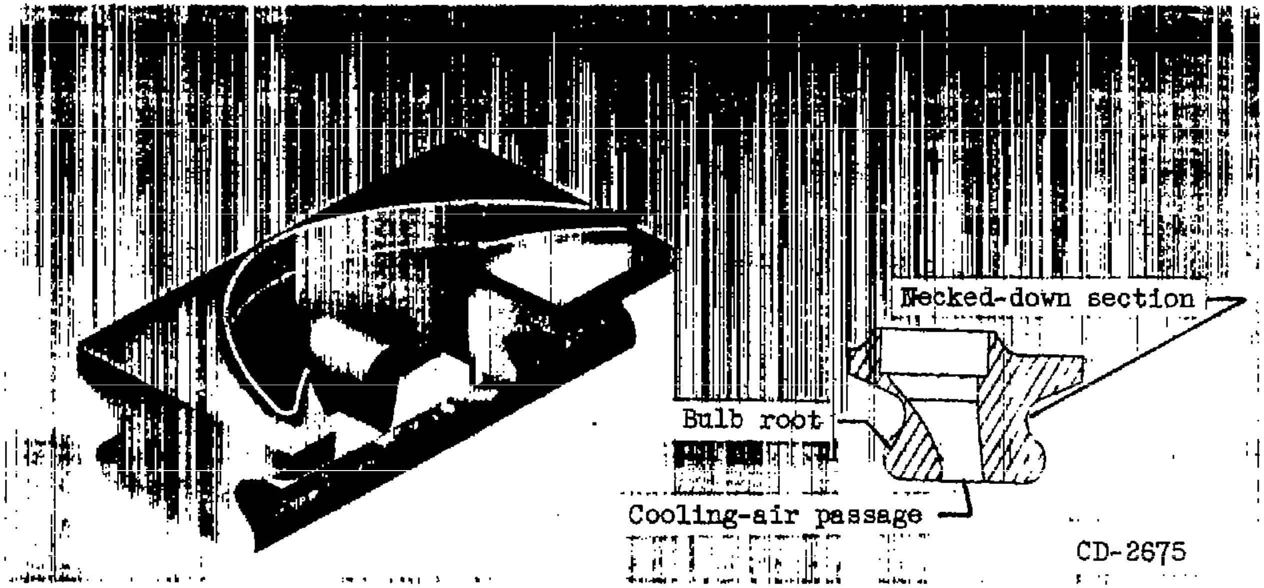


Figure 1. - Bulb-root-type cast air-cooled blade base.

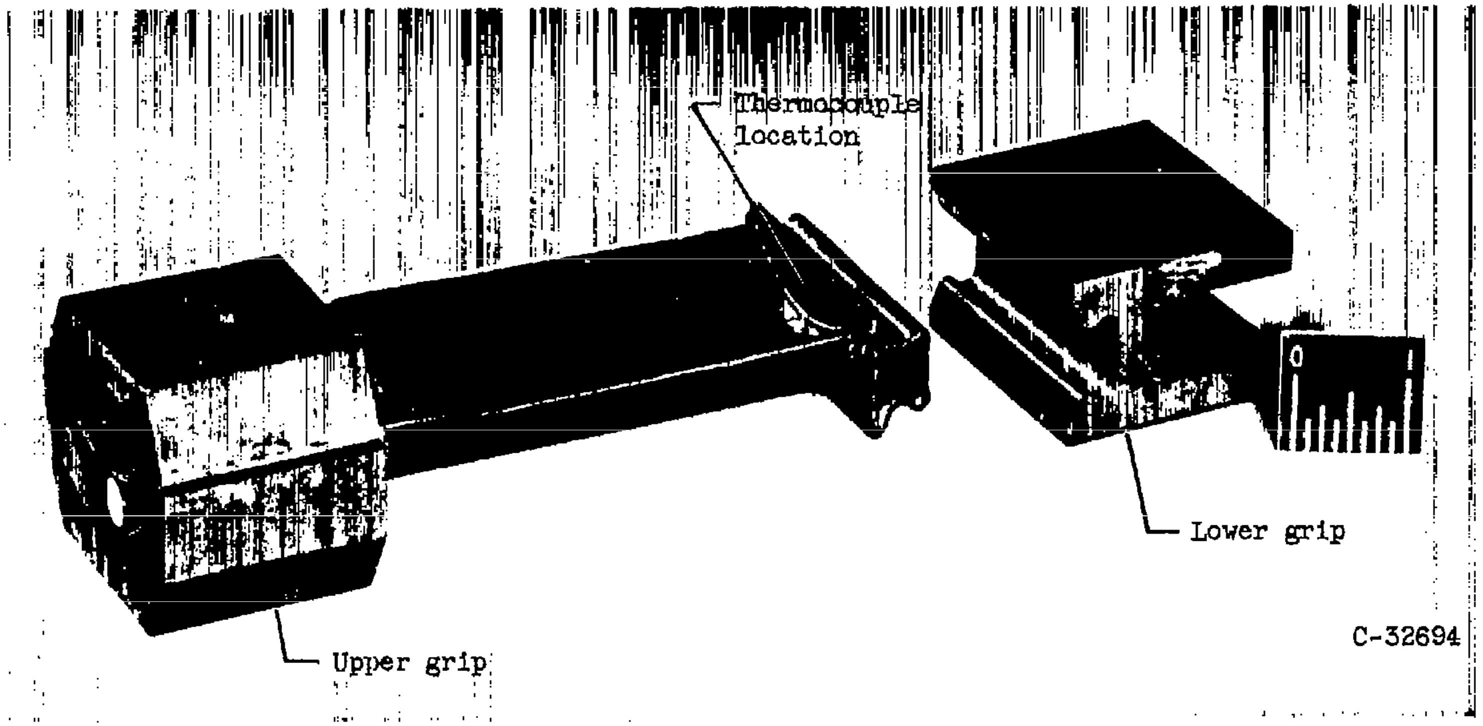


Figure 2. - Typical tensile-test specimen showing method of gripping blade shell and base.

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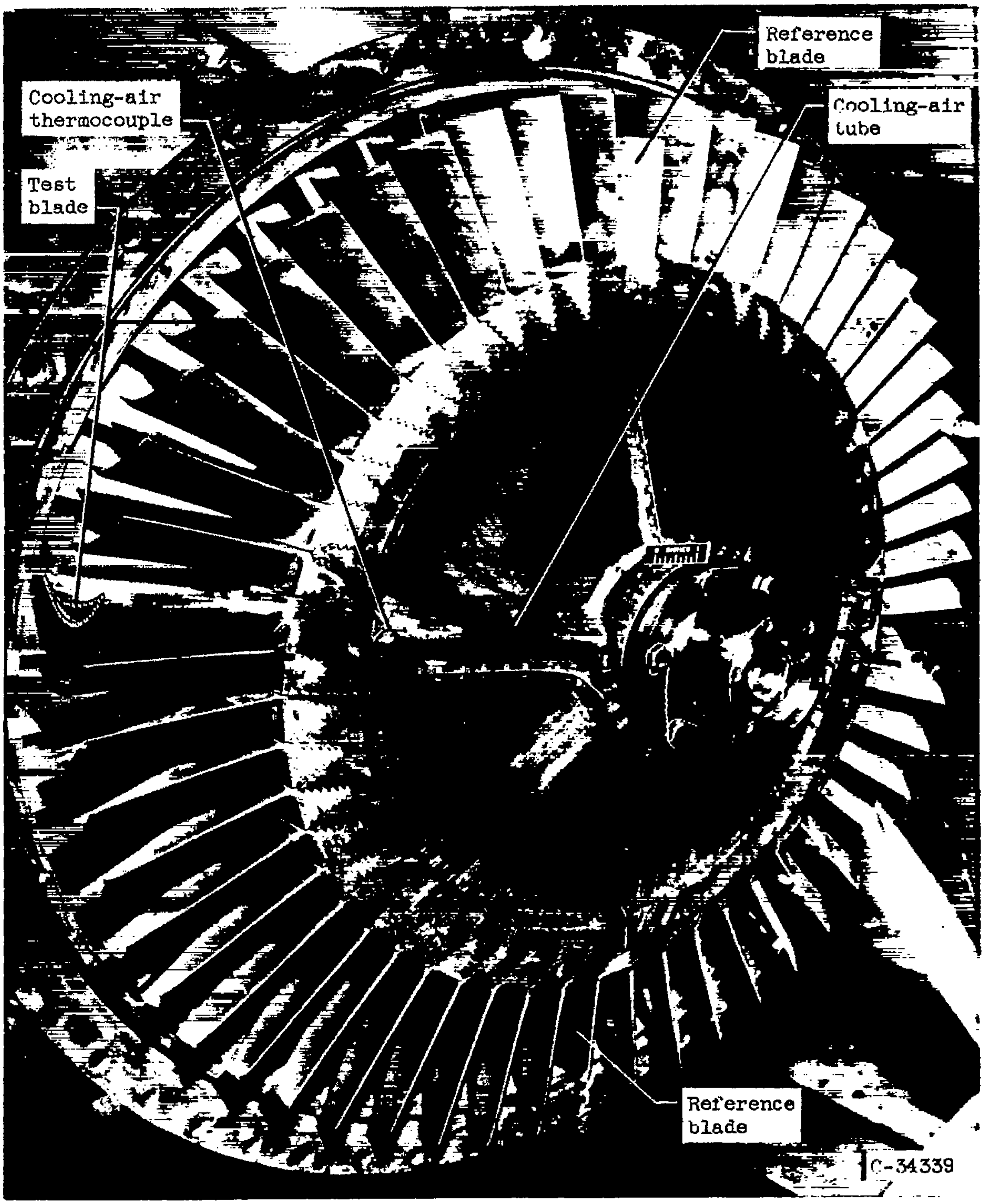


Figure 3. - Rotor installation for endurance testing showing test blade, instrumented reference blades, and cooling-air tube.

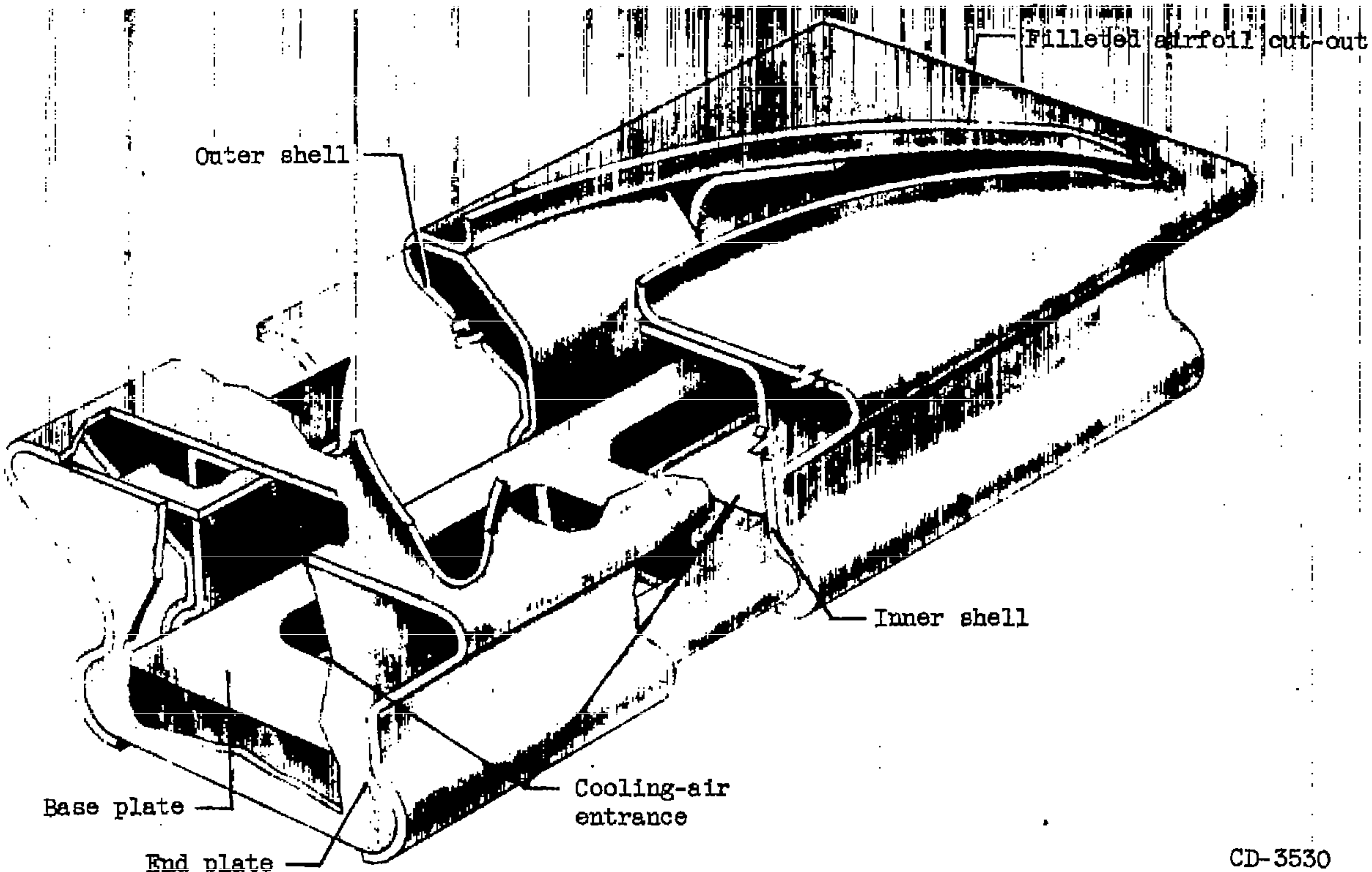


Figure 4. - Sheet-metal bulb-root-type air-cooled base, design 1.

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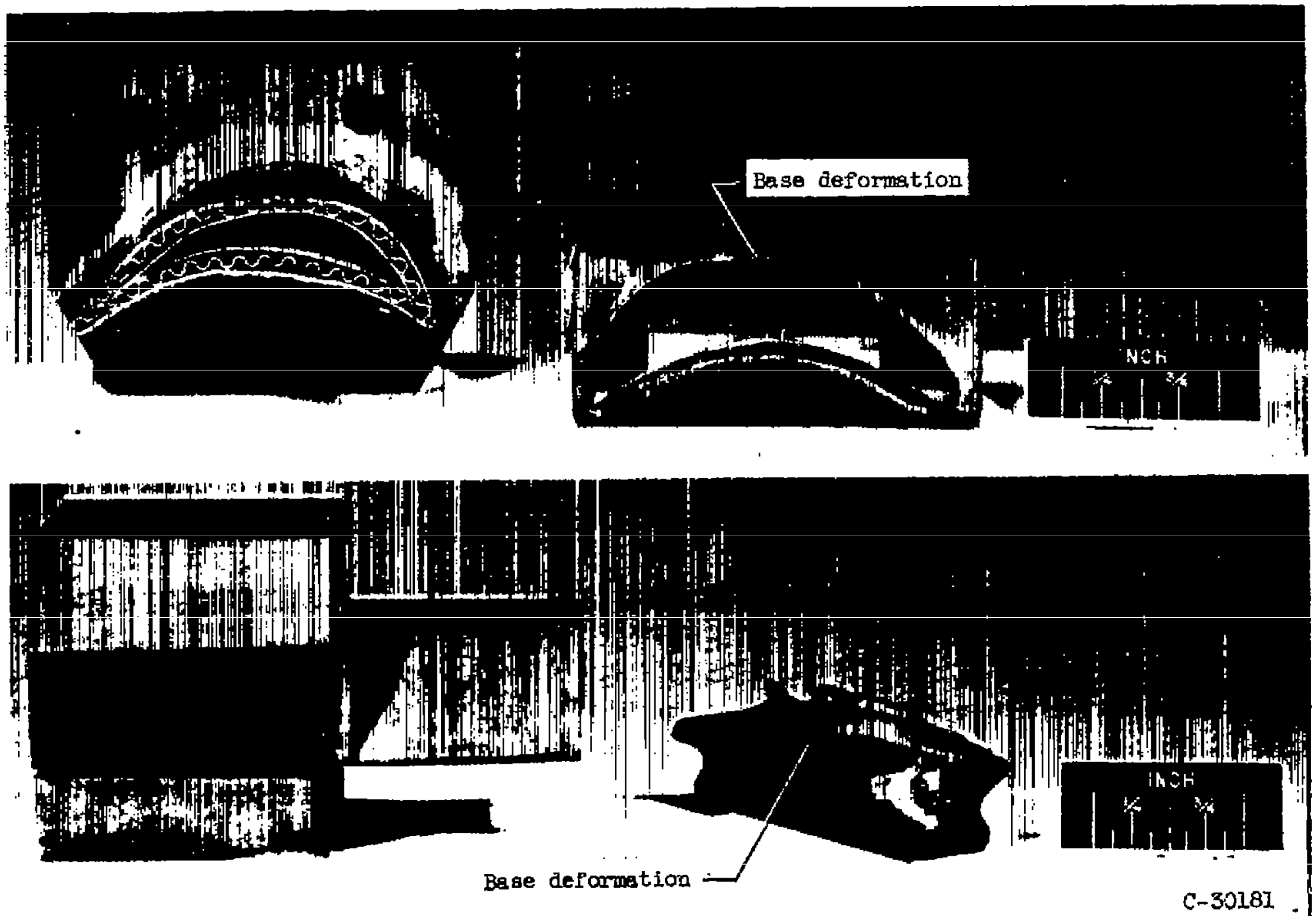
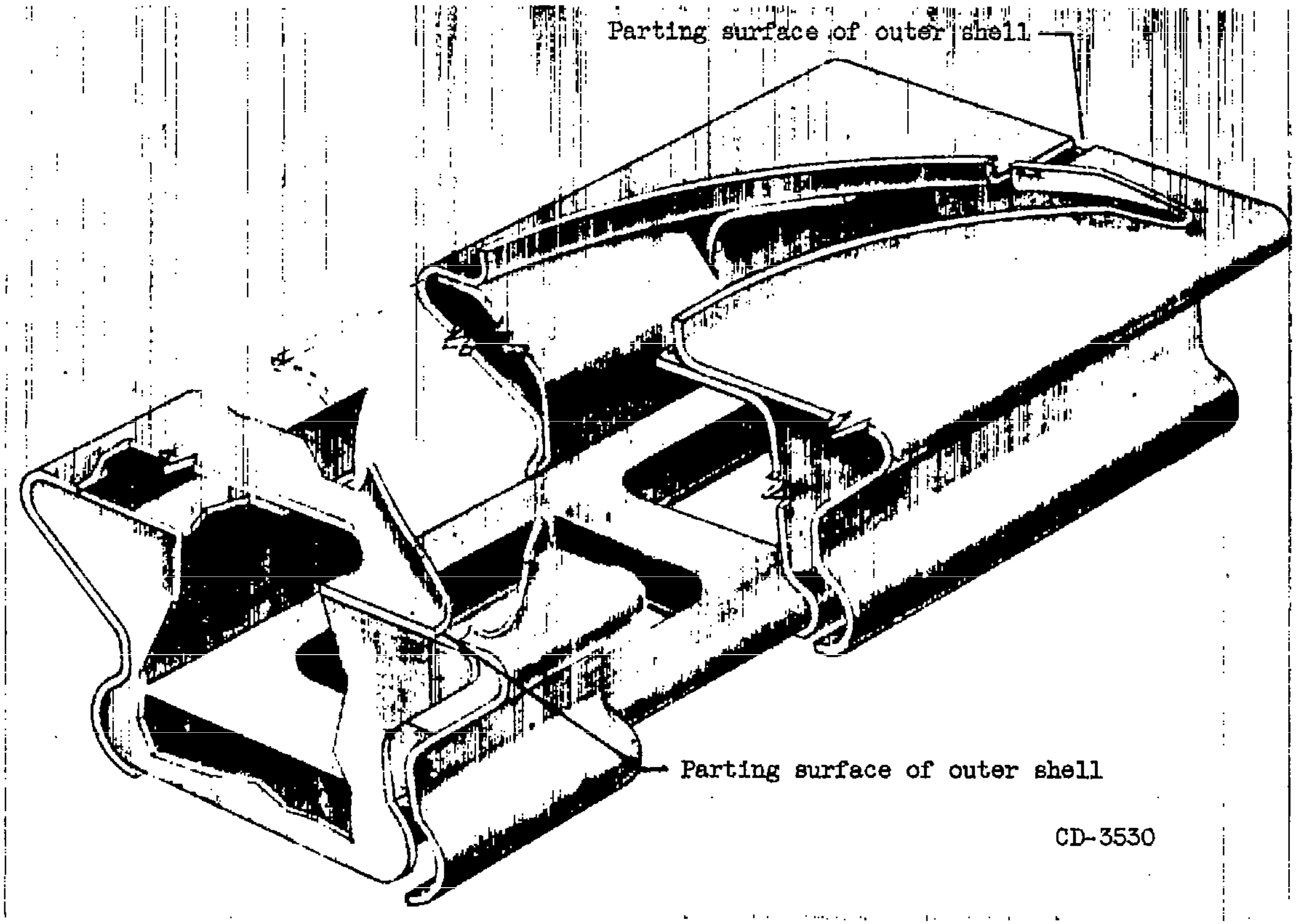
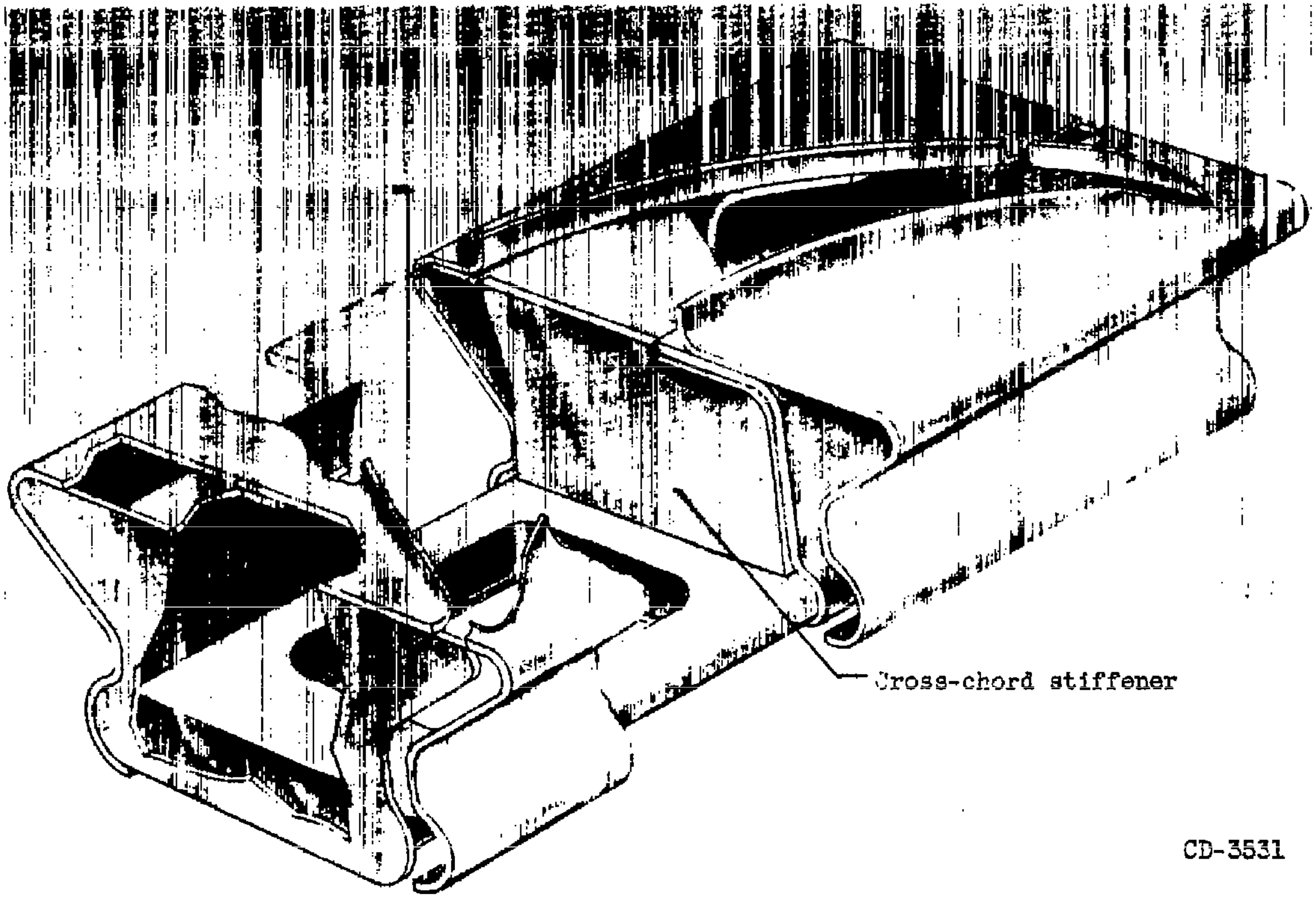



Figure 5. - Sheet-metal bulb-root-type air-cooled base, design 1, after tensile test showing deformed base and matching blade shell.




(a) Design 1, modification 1.

Figure 6. - Sheet-metal bulb-root-type air-cooled base.

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(b) Design 1, modification 2.

Figure 6. - Continued. Sheet-metal bulb-root-type air-cooled base.

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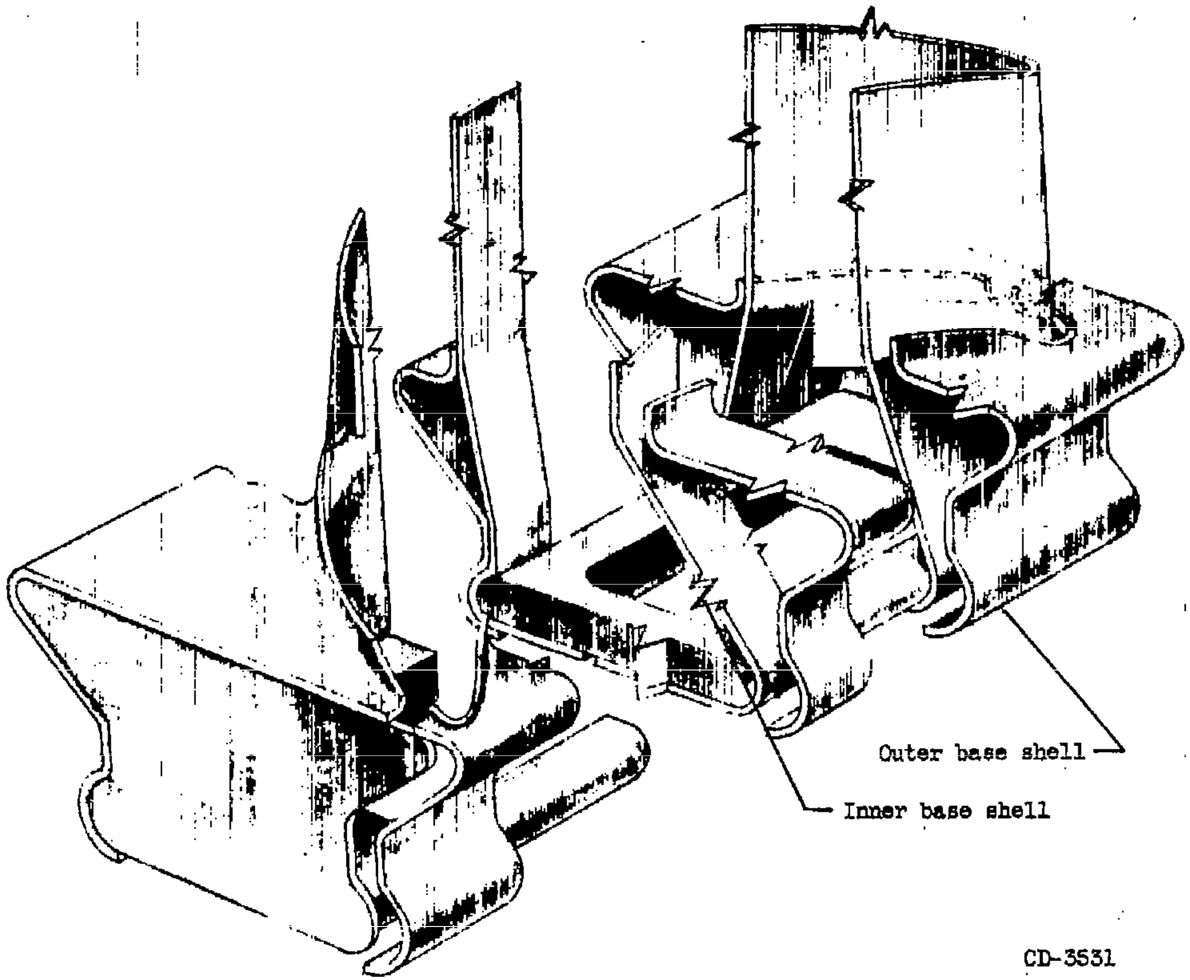


(c) Design 2.

Figure 6. - Continued. Sheet-metal bulb-root-type air-cooled base.

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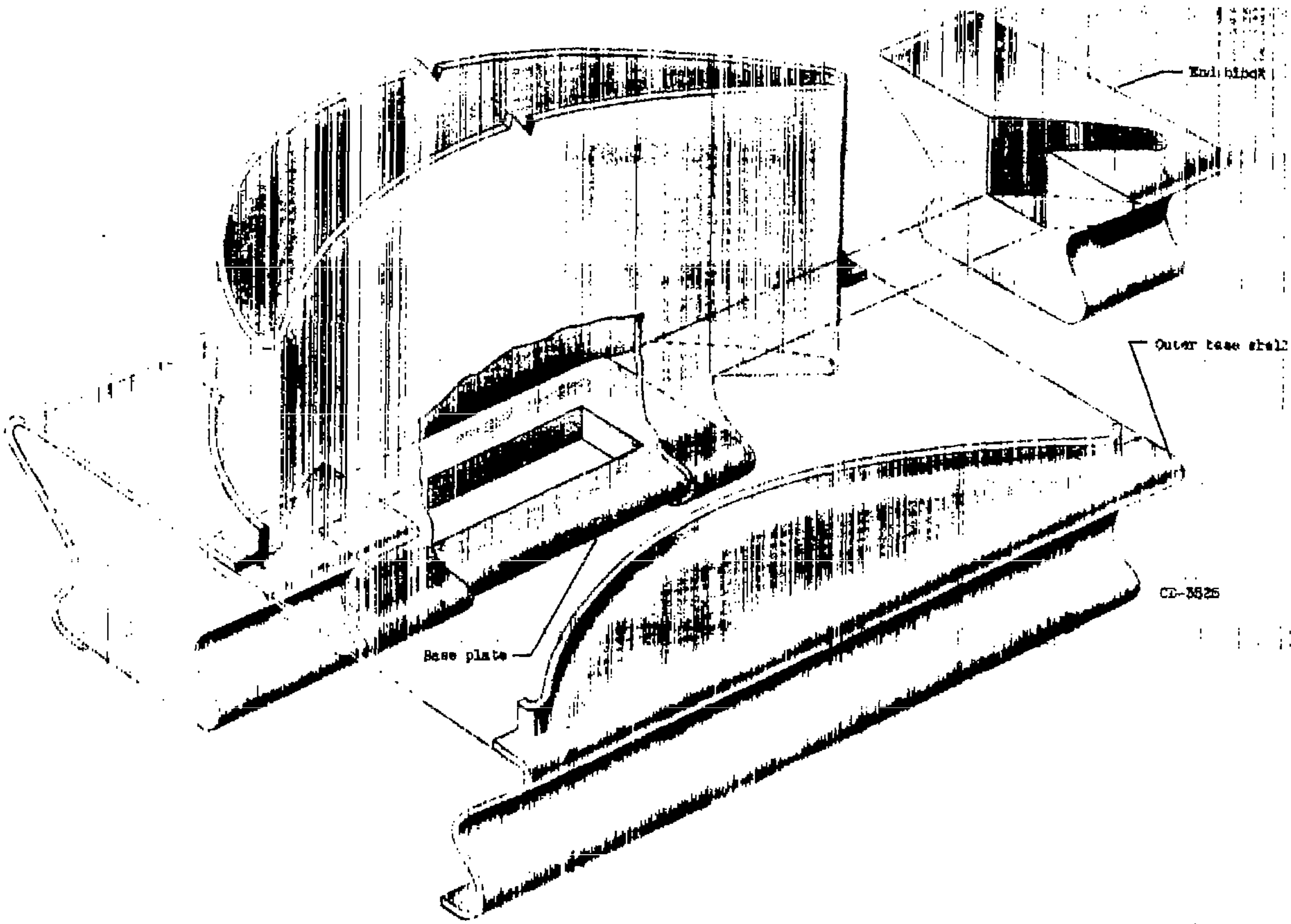


(d) Design 3.

Figure 6. - Continued. Sheet-metal bulb-root-type air-cooled base.

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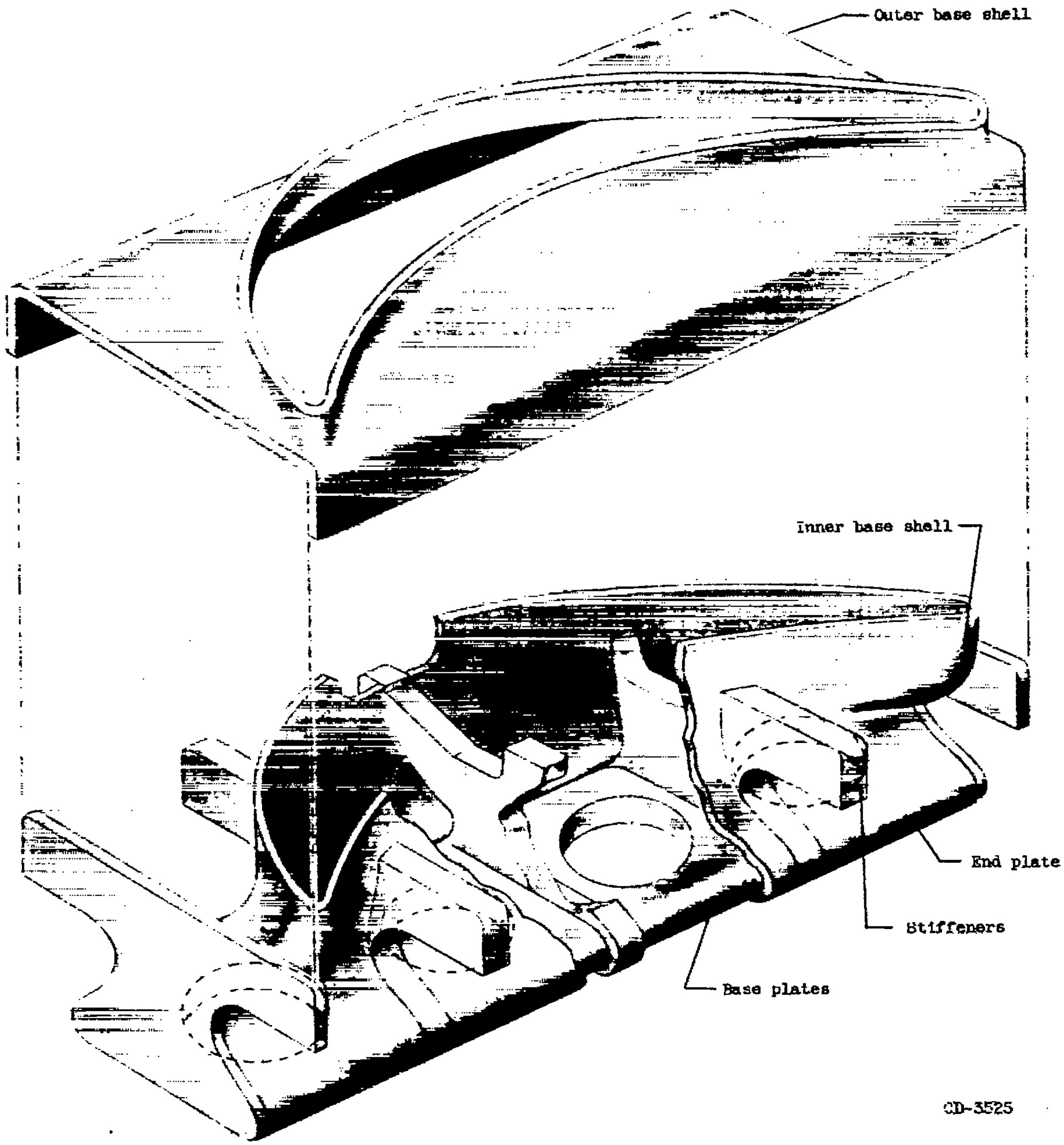


(e) Design 4.

Figure 6. - Concluded. Sheet-metal bulb-root-type air-cooled base.

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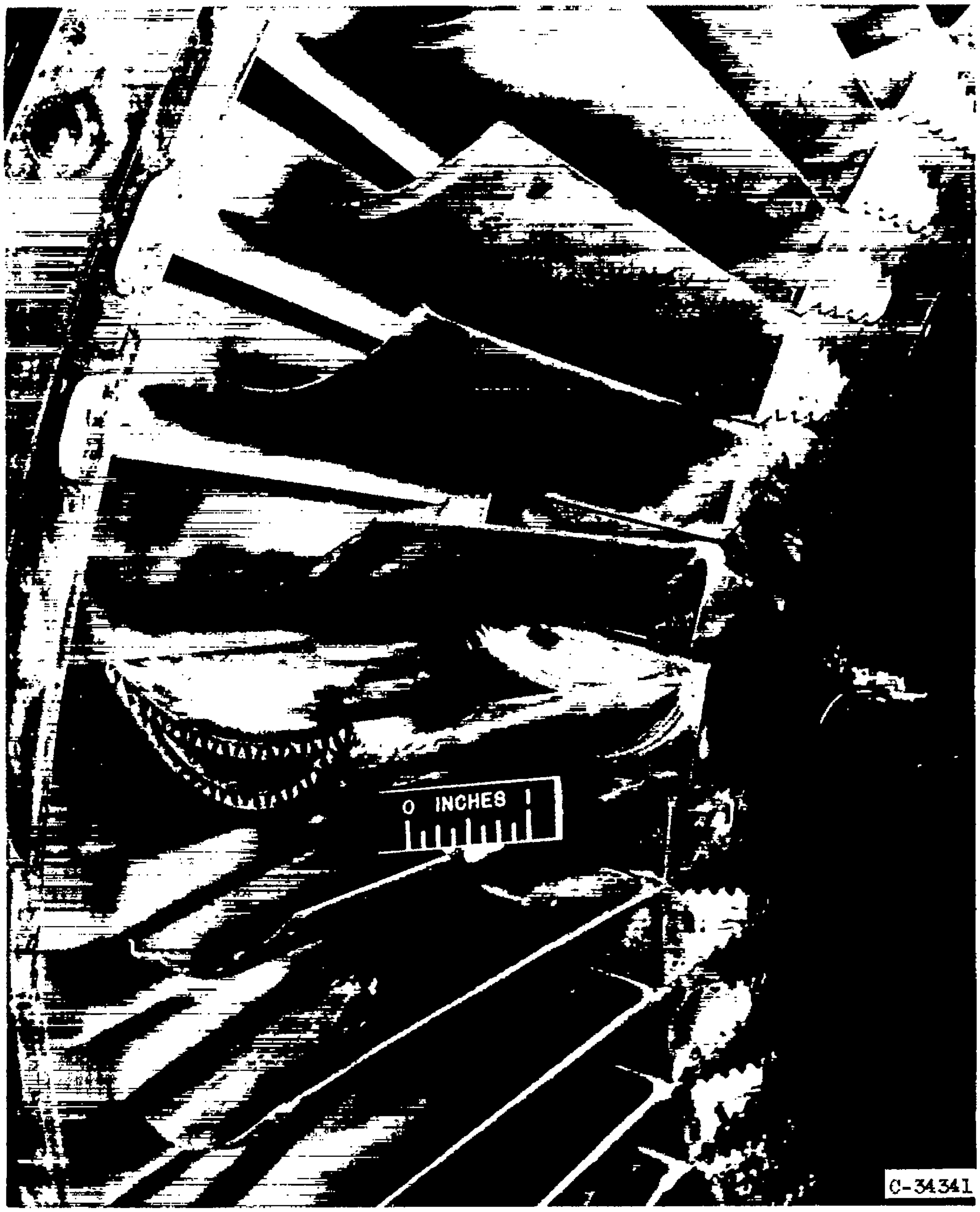


Figure 7. - Sheet-metal bulb-root-type air-cooled base, design 4, in test rotor after 10 hours of endurance operation.

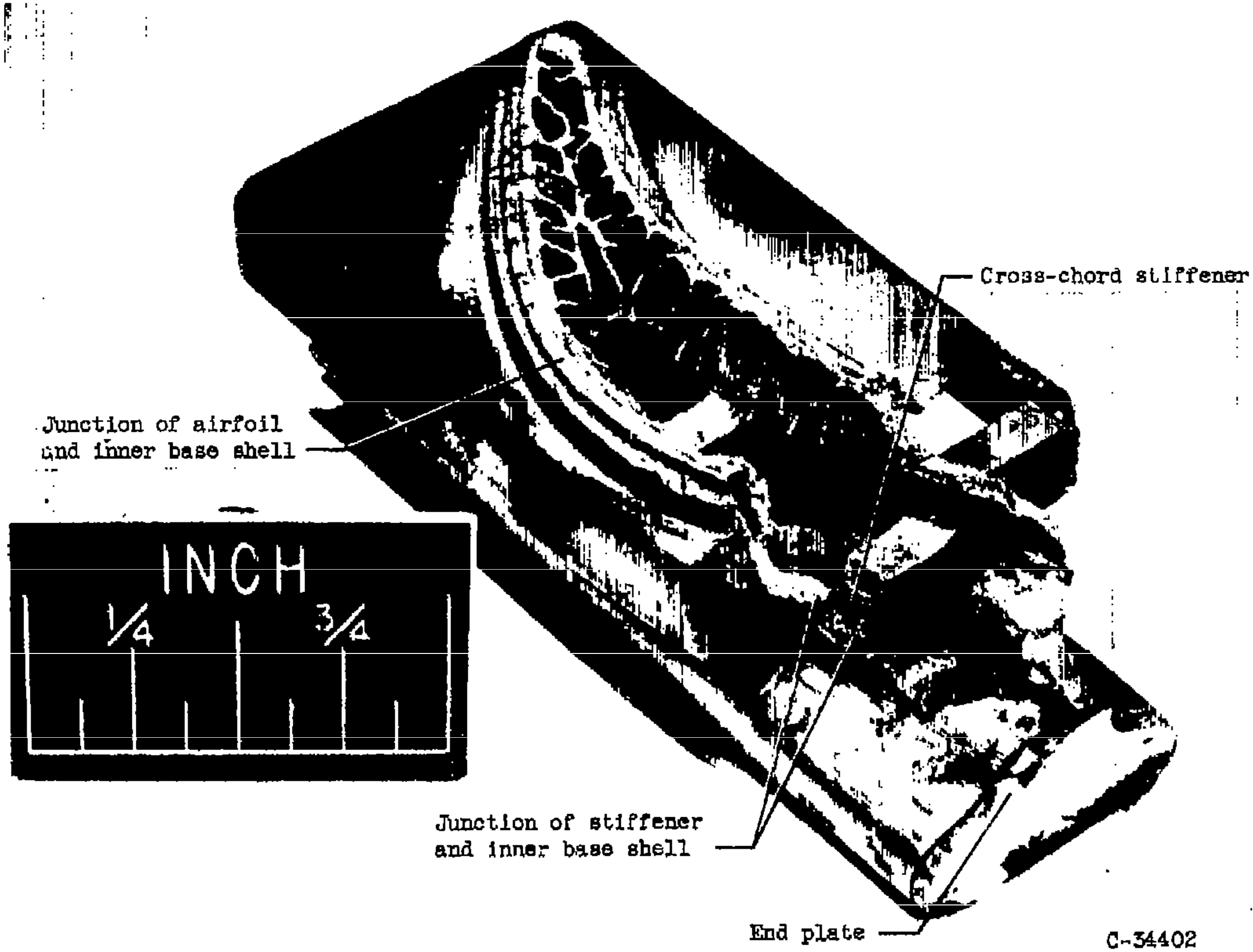


Figure 8. - Failed sheet-metal bulb-root-type air-cooled base, design 4, after 15 hours of endurance operation.

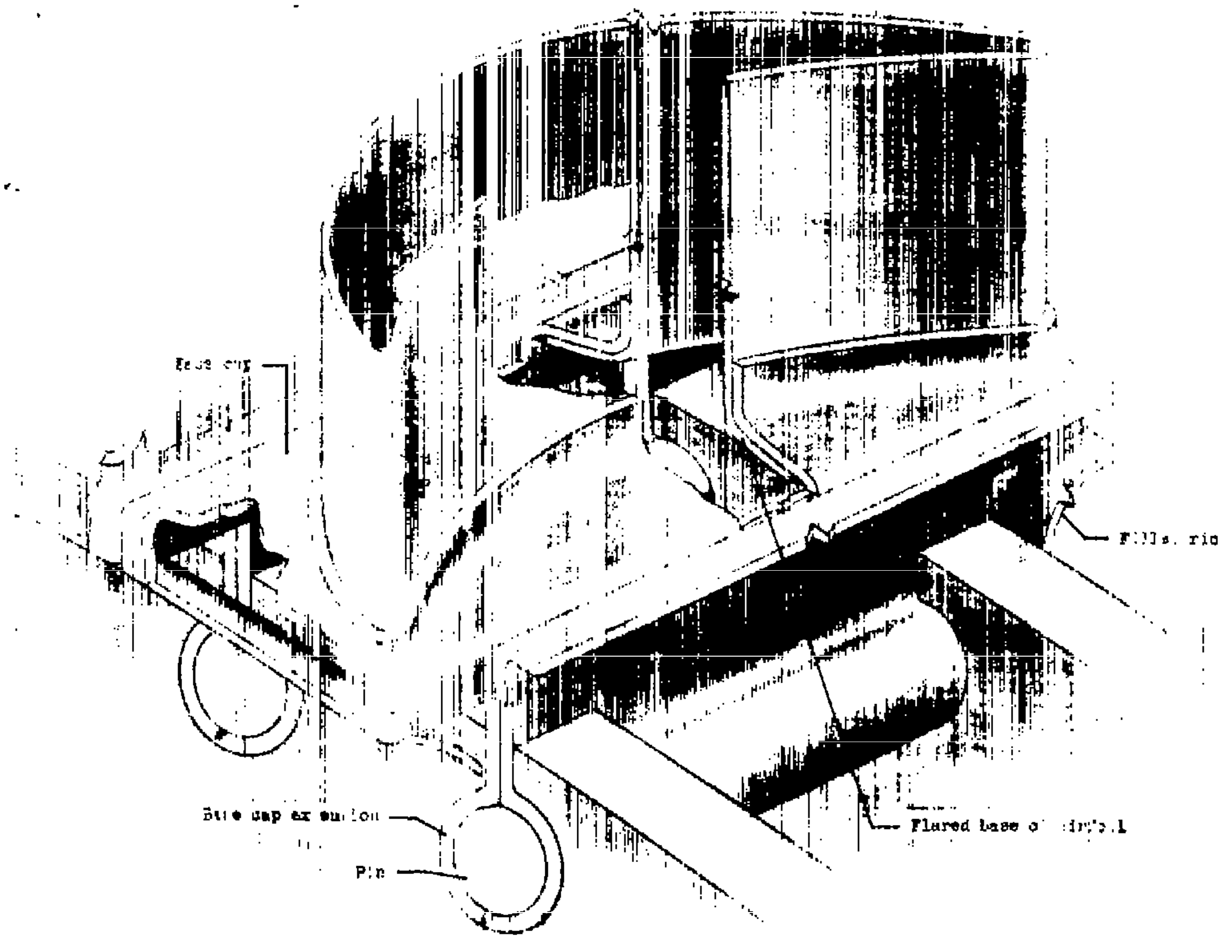


Figure 9. - Air-cooled pinned-type base design.

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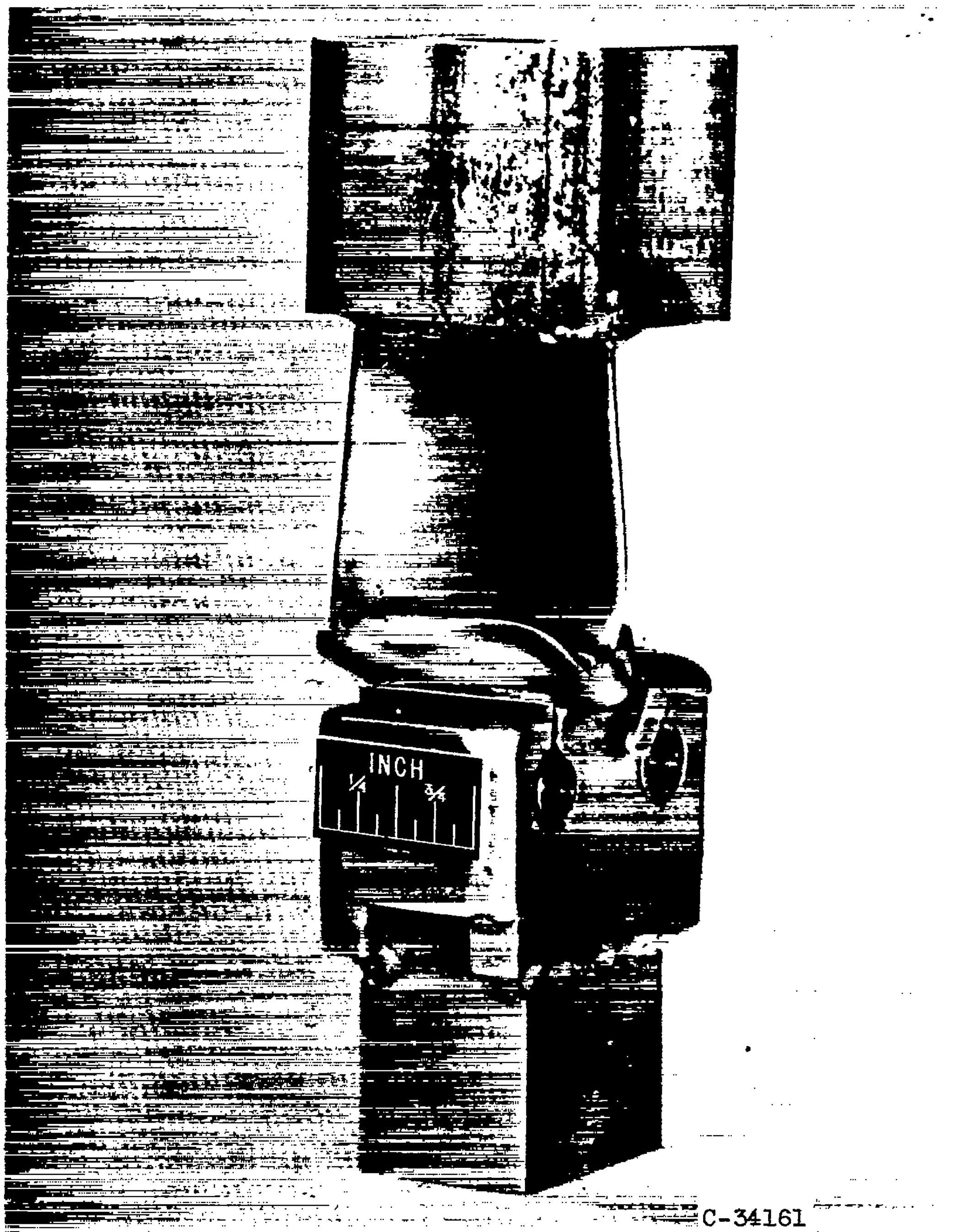


Figure 10. - Air-cooled pinned-type base design after tensile test failure.



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